Evolution of the protolunar disk from the impact to the assembling of the Moon

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The chemical and isotopic composition of the Earth's moon is inherited from the protolunar disk formed after a giant impact on the proto-earth. However, before the proto-moon can form, the disk must cool down first. During this cooling phase, major dynamical, chemical and isotopic restructuration may happen, and thus, the material that will get ultimately incorporated in the protomoon may show signatures potentially different from the average composition of the Earth or the impactor. Whereas numerous numerical simulations of the impact on the proto-Earth have been published, the evolution of the protolunar disk is largely unknown due to its intrinsic complex physics (needing the coupling the disk dynamics and thermodynamics including phase transition).

We have developed a viscous model of a two-phase protolunar disk, including phase transition, gravitational instability and Kelvin Helmoltz (KH) instability, due to the vertical velocity gradient between the gas and liquid phases to investigate the evolution of this disk on several 10^4 years, from the impact up to its ultimate cooling and assembling into a protomoon. We show that the location where the protomoon forms as well as its rate of accretion are completely controlled by the cooling process that is promoted by the onset of the Kelvin Helmoltz instability between the gas and liquid. In our model, the proto-moon never forms at the Roche Limit, but generally further away, in colder and more gravitationally instable regions. Because of their different viscosities, the gas and the liquid tend to decouple. Regions that are KH stable survive and keep a high temperature for an extended period of time whereas KH unstable regions tend to become gravitationally unstable on short timescales and lead to a fast spreading of material. This behavior between different disk regions implies a multi-stage formation of the proto-moon. We find that the initial vapor/liquid ratio has a major impact on the final evolution of the disk as it controls the onset of the KH and gravitational instabilities). We explore different initial conditions for the protolunar disk and discuss the disk evolution in the different cases.